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13. ABSTRACT (Maximum 200 words)

The overall objective of this research is to identify and control the basic physical mechanisms responsible for light emission in synthesized semiconductor and dielectric materials. Investigations are to be performed in order to develop new device concepts and provoke new ideas for optoelectronic applications. Specifically this research involves: 1) analyzing the physical origin of light emission from nanometer-size semiconductor particles; 2) studying the light emission of rare earth dopants in semiconductors and dielectrics and; 3) determining the feasibility of developing light emitting devices based upon the novel properties of such materials.

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Luminescence in Synthesized Semiconductor and Dielectric Materials

FINAL PROGRESS REPORT

Dr. R. M. Kolbas

September 20, 1996

U. S. Army Research Office

DAAH04-93-D-0003

North Carolina State University

A. STATEMENT OF THE PROBLEM STUDIED

The overall objective of this research is to identify and control the basic physical mechanisms responsible for light emission in synthesized semiconductor and dielectric materials. Investigations are to be performed in order to develop new device concepts and provoke new ideas for optoelectronic applications. Specifically this research involves: 1) analyzing the physical origin of light emission from nanometer-size semiconductor particles; 2) studying the light emission of rare earth dopants in semiconductors and dielectrics and; 3) determining the feasibility of developing light emitting devices based upon the novel properties of such materials.

B. SUMMARY OF THE MOST IMPORTANT RESULTS

a) Light Emission from Silicon Nanoparticles:

Light emission characteristics from silicon nanoparticles consisting of a crystalline core encased in an amorphous oxide shell are presented. The particles were thermally oxidized in the open atmosphere at 800 °C for times from 5 to 160 minutes in order to decrease the Si core dimensions. Photoluminescence spectra, at low excitation levels, reveal that the light emission shifts to shorter wavelengths as the oxidation time is increased. At high excitation levels, photoluminescence spectra show little or no shift. These results indicate that there are at least two mechanisms involved with light emission from Si nanoparticles, one associated with quantum size effects and another which is independent of size distribution.

b) Light Generation and Waveguiding In Er Doped GaN Epilayers:

We reported on some of the first observations of infrared light generation of Er atoms incorporated in GaN epilayers. The Er atoms were introduced into the epilayers either by ion-implantation or during epitaxial growth. For the ion-implanted epilayers, there was additional implantation of oxygen followed by annealing at 650 or 700 °C. The epilayers were optically excited using an argon-ion laser emitting at a wavelength of 457.9 μm and infrared spectra were measured at 6, 77 and 300 K. The spectra are centered at 1.54 μm and display many of the allowed transitions between levels of the $^4I_{13/2}$ manifold and the $^4I_{15/2}$ ground state manifold typical of the Er^{3+} configuration. The luminescence is nearly as intense at room temperature as it is at 77 K. This result is consistent with experiments indicating that wide bandgap materials, such as GaN (~3.4 eV), tend to suppress the temperature dependence of the Er luminescence. Preliminary designs for waveguiding structures of 1.54 μm light in the GaN epilayers are also being investigated.

C. LIST OF ALL PUBLICATIONS AND TECHNICAL REPORTS

1. Dahua Zhang, P. D. Milewski, D. J. Lichtenwalner, R. M. Kolbas, A. I. Kingon and J. M. Zavada, "Origin of Light Emission from Silicon Nanoparticles," *Proceedings of the Fourth International Conference on Solid-State and Integrated-Circuit Technology* (Beijing, China), G. L. Baldwin, Z. Li, C. C. Tsai and J. Zhang, Eds., pp. 54-56, 1995.

2. Dahua Zhang, T. Zhang, R. M. Kolbas and J. M. Zavada, "Optical Characteristics of Erbium Doped AlGaAs-GaAs Heterostructures," *Proceedings of the Fourth International Conference on Solid-State and Integrated-Circuit Technology* (Beijing, China), G. L. Baldwin, Z. Li, C. C. Tsai and J. Zhang, Eds., pp. 506-508, 1995.

3. J. M. Zavada, S. J. Pearton, C. R. Abernathy, R. J. Shul, R. G. Wilson and Dahua Zhang, "Microdisc Laser Structures Formed in III-V Nitride Epilayers," *Proceedings of Topical Workshop on III-V Nitrides* (Nagoya, Japan), September 22, 1995.

4. J. M. Zavada and Dahua Zhang, "Luminescence Properties of Erbium in III-V Compound Semiconductors," *Solid-State Electronics*, Vol. 38, No. 7, pp. 1285-1293, 1995.

5. J. M. Zavada, Dahua Zhang, C. R. Abernathy, S. J. Pearton, R. G. Wilson and R. N. Schwarz, "Light Generation and Waveguiding in Er Doped GaN Epilayers," *Material Research Society Fall Meeting*, Boston, MA, Nov. 28-Dec. 2, 1994.

6. J. M. Zavada and Dahua Zhang, "Luminescence of Erbium Atoms in III-V Compound Semiconductors," State-of-the-Art Program on Compound Semiconductor (SOTAPOCS) XXI, Miami Beach, FL, October 9-14, 1994, *Proceedings of Electrochemical Society Symposium*, 1995.

7. R. M. Kolbas, T. Zhang, D. E. Moxey and D. Zhang, "Molecular Beam Epitaxial Growth and Energy Transfer Processes in Erbium Doped GaAs/AlGaAs Heterostructures," *Rare Earth Doped Optoelectronic Materials Workshop*, Malibu, CA, June 16-17, 1994.

8. D. Zhang, P. D. Milewski, D. J. Lichtenwalner, R. M. Kolbas, A. I. Kingon and J. M. Zavada, "Thermal Oxidation Study of Light Emission from Silicon Nanoparticles," *1994 March Meeting of the American Physical Society*, Pittsburgh, PA, March 21-25, 1994.

9. D. Zhang, P. D. Milewski, D. J. Lichtenwalner, R. M. Kolbas, A. I. Kingon and J. M. Zavada, "Light Emission from Thermally Oxidized Silicon Nanoparticles," *Applied Physics Letters*, Vol. 65, No. 21, pp. 2684-2686, 1994.

The following publications and presentations with Dr. Subash Krishnankutty were supported by this contract and also ARO DAAH 04-93-G-0254 and ONR N00014-93-1-0665. Details of the following can be found in the reports covering ARO DAAH 04-93-G-0254.

10. "Investigation of In-situ Doping Effect on GaN Epitaxial Growth in a Mass Production Scale Multi-Wafer-Rotating-Disc Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, C. S. Chern, W. Kroll, R. A. Stall, C.-Y. Hwang, M. Schurman, Y. Li, W. E. Mayo, Y. Yu, S. Krishnankutty, I. K. Shmagin, R. M. Kolbas and S. J. Pearton, J. Vac. Sci. Tech. B, Vol. 13, p. 2075, Sept./Oct. 1995.

11. "P-Type GaN Epitaxial Growth on c-Sapphire Substrates in a Production Scale Multi-Wafer Rotating Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, P. Zawadzki, C. S. Chern, W. Kroll, R. A. Stall, C.-Y. Hwang, Y. Li, M. Schurman, W. E. Mayo, Y. Yu, S. J. Pearton, S. Krishnankutty, and R. M. Kolbas, presented at the 1995 Electronic Materials Conference, Charlottesville, VA 1995, and published in J. Electrochem. Soc. Vol. 142, p. L163, Sept. 1995.

12. "Effect of Shroud Flow on High Quality $In_xGa_{1-x}N$/GaN Double Heterojunction deposition in a Production Scale Multi-Wafer-Rotating-Disc MOCVD Reactor," C. Yuan, T. Salagaj, R. A. Stall, M. Schurman, C. Y. Hwang, Y. Li, W. E. Mayo, Y. Lu, S. Krishnankutty and R. M. Kolbas, submitted to J. Electronic Materials.

13. "Investigation of High Quality P-Type GaN and InGaN from Multi-Wafer-Rotating-Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, C. S. Chern, W. Kroll, R. A. Stall, C.-Y. Hwang, M. Schurman, Y. Li, W. E. Mayo, Y. Yu, S. Krishnankutty, R. M. Kolbas and S. J. Pearton, presented at the Spring Meeting of the 1995 Materials Research Society, San Francisco, California.

14. "Investigation of High Quality P-Type GaN and InGaN from Multi-Wafer-Rotating-Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, C. S. Chern, W. Kroll, R. A. Stall, C.-Y. Hwang, M. Schurman, Y. Li, W. E. Mayo, Y. Yu, S. Krishnankutty, R.

M. Kolbas and S. J. Pearton, Materials Research Society, Spring Symposium, San Francisco, California, 1995.

15. "Investigation of the photoluminescence characteristics of Mg:GaN and Zn:InGaN," S. Krishnankutty, I. K. Shmagin, R. M. Kolbas, C. Yuan, and R. A. Stall, presented at the Wide Bandgap Nitride Workshop, Nagoya, Japan, Sept. 1995.

16. "High Quality P-type GaN and InGaN Epitaxial Growth on c-Sapphire Substrates in a Production Scale Multi-Wafer-Rotating Disc MOCVD Reactor," C. Yuan, T. Salagaj, A. Gurary, A. G. Thompson, W. Kroll, R. A. Stall, M. Schurman, C. Y. Hwang, Y. Li, Y. Lu, W. E. Mayo, S. Krishnankutty, R. M. Kolbas and S. J. Pearton, Invited talk at the meeting of the ElectroChemical Society, Chicago (Oct. 1995)

D. REPORT OF INVENTIONS:

None

D. PARTICIPATING SCIENTIFIC PERSONNEL (and advanced degrees earned while employed on the project)

Dr. Dahua Zhang

Dr. Subash Krishnankutty

Dr. Robert M. Kolbas

BIBLIOGRAPHY

APPENDIXES